THERMAL WAVE IMAGING OF AIRCRAFT STRUCTURES

L.D. Favro, T. Ahmed, Xiaoyan Han, Li Wang,
Xun Wang, Yingxia Wang, P.K. Kuo, and R.L.Thomas
Department of Physics and Institute for Manufacturing Research
Wayne State University, Detroit, MI 48202, USA

and

S.M. Shephard
Thermal Wave Imaging, Inc.
18899 W. 12 Mile Rd.
Lathrup Village, MI 48076

INTRODUCTION

In a previous report [1], we introduced the application of thermal wave imaging to adhesion disbonds and corrosion in aircraft. In the present paper, we describe the application of pulse-echo thermal wave imaging to NDT of aging aircraft. The technique uses high-power photographic flash lamps as a heat source and an IR video camera as a detector. The flash lamps launch pulses of heat into the skin of the aircraft and the IR camera images the returning thermal wave reflections from subsurface defects. The system also includes electronic hardware and software for carrying out the time-gated imaging and real time analysis of the defects. It also has the ability to image large areas in short times. The current inspection speed enables the imaging of over 90 feet of a 16" strip of aircraft per hour. Here we present some examples of airframe defects, both for metal and composite structures.

THERMAL WAVE IMAGES

In Fig. 1 we show an example of a thermal wave image of a region of the FAA's B737 aircraft testbed, located in the FAA-AANC hangar at Albuquerque. This area, and other areas of the aircraft imaged in each of the following figures were first painted with a water soluble paint to improve the heat absorption and emission. The region imaged in Fig. 1 was chosen to be illustrative of one for which there is minimal subsurface corrosion and disbonding. Three images were overlapped to comprise Fig. 1, and each was taken using a delay time of 0.17 sec following the application of a spatially uniform, ~4 msec duration heat pulse on the surface of the aircraft.

In contrast to Fig. 1, Fig. 2 is a thermal wave image of a region of the aircraft which contains verified subsurface defects. This image, also taken at a gate time of 0.17 sec, shows regions of corrosion and/or disbonding (e.g.the bright region along stringer E-E, to the right of frame station B-B and the "staircase-shaped" bright region to the left of B-B, above E-E). These defects have also been seen by ultrasonic imaging [2].

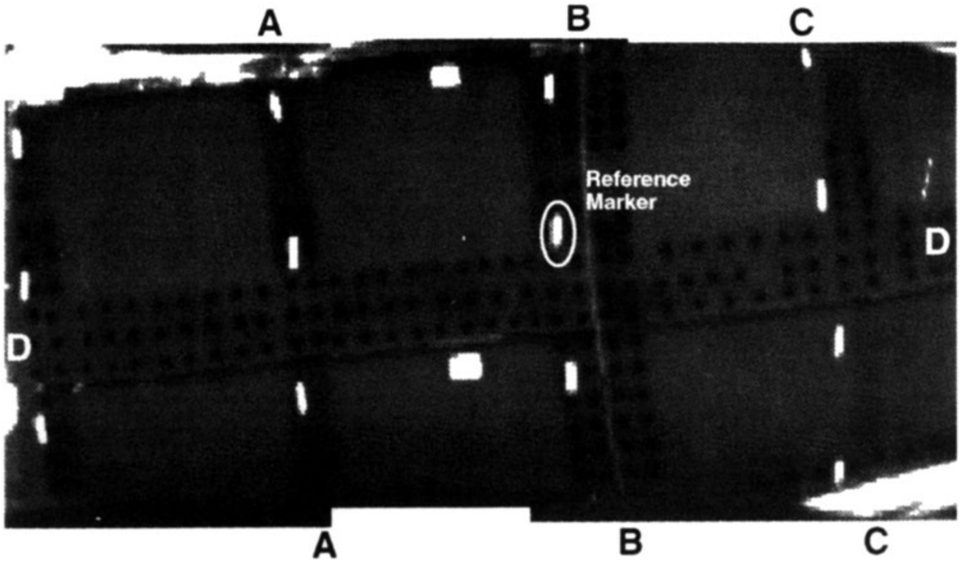

Fig. 1 Example thermal wave image showing subsurface structure (e.g. bonded lapsplice: D-D; a well-bonded tear strap; A-A, a butt joint; B-B, etc.). This image was taken using a delay time of 0.17 sec following the application of a spatially uniform, ~4 msec duration heat pulse on the surface of the aircraft. With the possible exception of a section of the tear strap C-C, no subsurface corrosion or disbonds are apparent in this image. The various white patches in the image are reference markers applied to the surface of the aircraft.

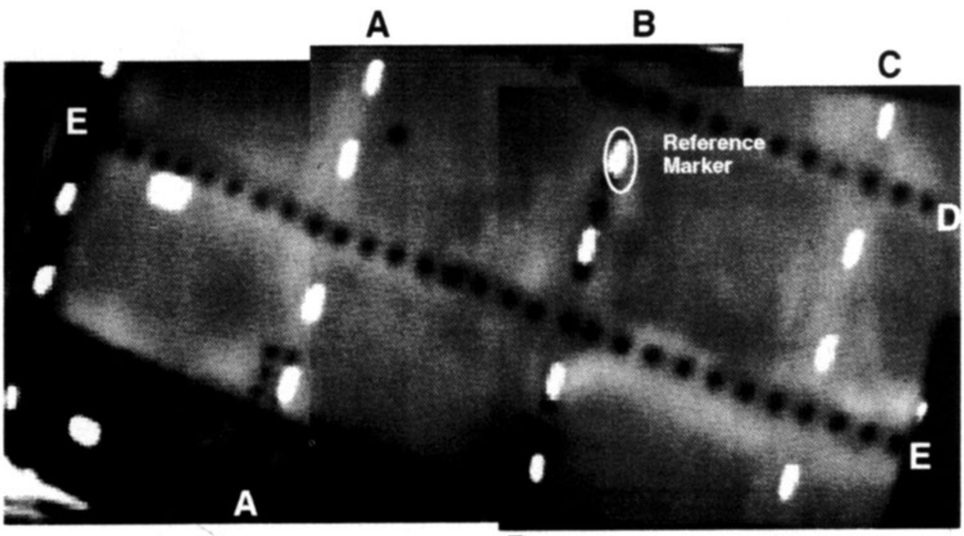

Fig. 2 Thermal wave image (also taken at a gate time of 0.17 sec) showing regions of corrosion and/or disbonding (e.g., the bright region along stringer E-E, to the right of frame station B-B, and the "staircase-shaped" bright region to the left of B-B, above E-E). These regions have also been seen by ultrasonic imaging [2]. The various white patches in the image are reference markers applied to the surface of the aircraft.

Figure 3 shows a series of thermal wave images taken at seven successively longer gate times following a single heat pulse. These images are shown to illustrate the ability of thermal waves to reveal increasingly deeper features as the time delay following the heat pulse increases. The top image repeats the experiment illustrated in Fig. 2, and the succeeding images show progressively deeper features beneath the surface. The bonded structures are only evident at the latest gate times, and the tear strap to the right side of these images (see also B-B in Fig. 2 above) appears not to be well bonded. It may also be noted that the images grow progressively more blurred as the delay gate time for the image is lengthened. This effect is the result of the lateral heat diffusion during the thermal wave propagation [3]. It has been shown [4] that it is possible to apply an inverse thermal wave scattering algorithm to greatly reduce the blurring of similar thermal wave images, and that the algorithm can be implemented in less than a minute on a personal computer.

Figure 4 shows a thermal wave image taken in a region for which there is a bonded doubler beneath the outer skin of the fuselage. The bright regions of the thermal wave image indicate the presence of corrosion and/or disbonding of the doubler, which extends inward from the edge of the doubler.

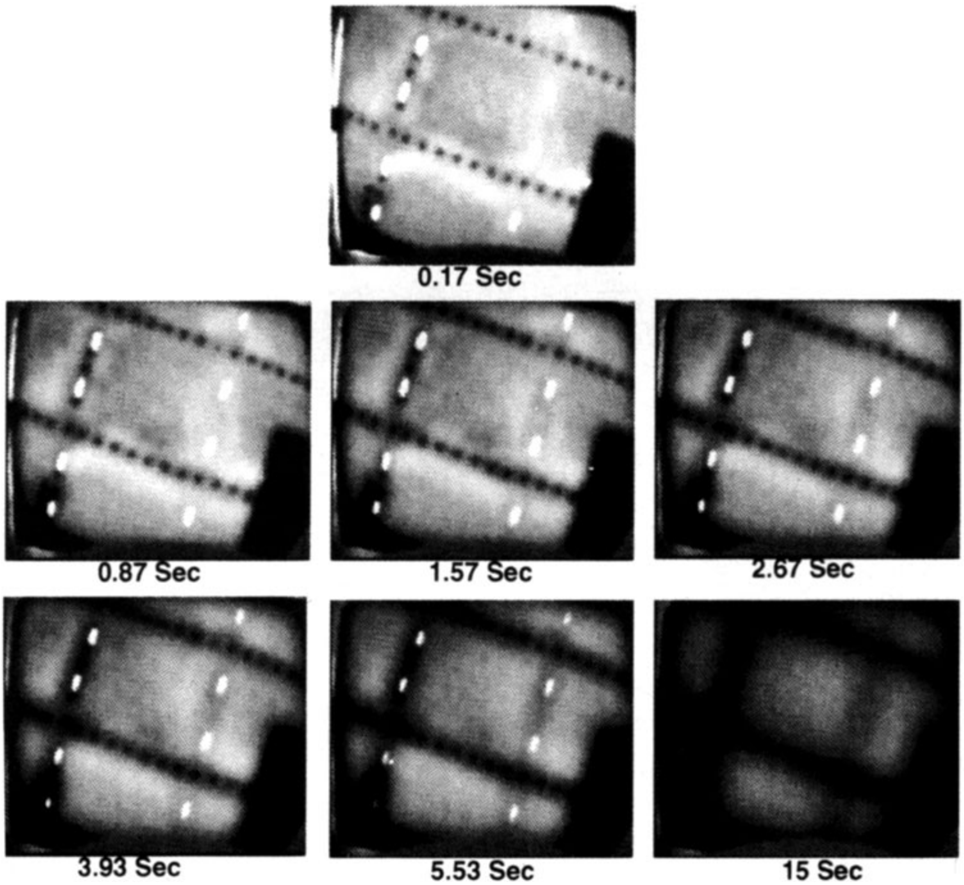

Fig. 3 Series of thermal wave images taken at seven successively longer gate times following a single heat pulse. The top image repeats the experiment illustrated in Fig. 2, and the succeeding images show progressively deeper features beneath the surface. The bonded structures are only evident at the latest gate times, and the tear strap to the right side of these images (see also B-B in Fig. 2 above) appears not to be well bonded. The various white patches in the image are reference markers applied to the surface of the aircraft.

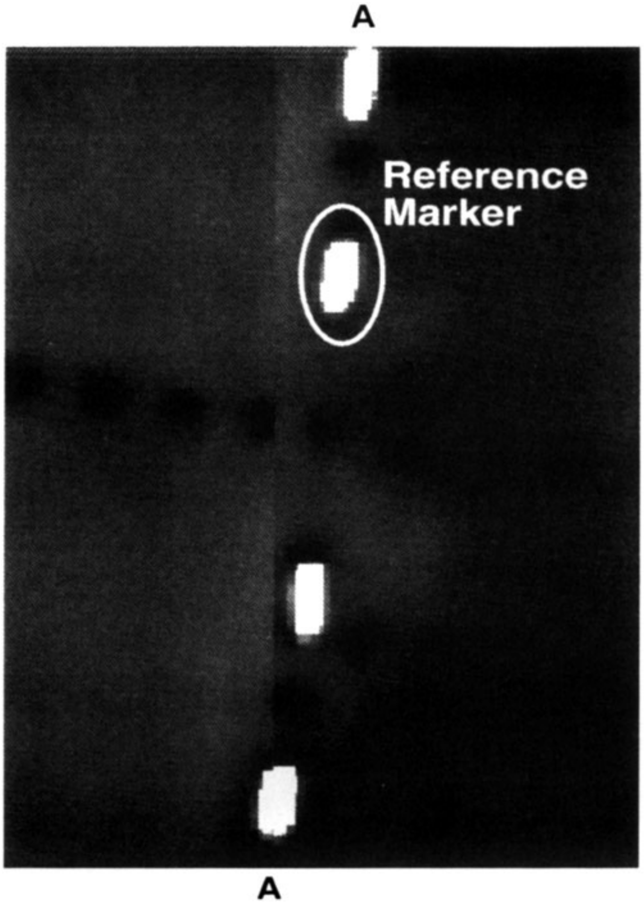

Fig. 4 Thermal wave image (also taken at a gate time of 0.17 sec) showing a boundary A–A, to the right of which is an internal doubler beneath the skin of the fuselage. The irregularly shaped ligher regions to the right of A-A are indicative of corrosion and/or disbonding intruding from the edge of doubler. The various white patches in the image are reference markers applied to the surface of the aircraft.

The FAA's B737 aircraft testbed also contains a region of fuselage on which has been applied a boron-epoxy composite patch reinforcement, such as is currently being utilized by the Air Force to reinforce weep holes areas in wing structures of C-141 aircraft. This particular patch was prepared with a number of artificial subsurface planar defects, and was applied in a region of the B737 located at the intersection of a stringer and frame station. Figure 5 presents thermal wave images of this composite patch, showing the thermal wave reflections from the artificial defects, from regions of weak bonding above some of the fasteners along the stringer, and (at later gate times) from the stringer and frame station beneath both the patch and the fuselage skin.

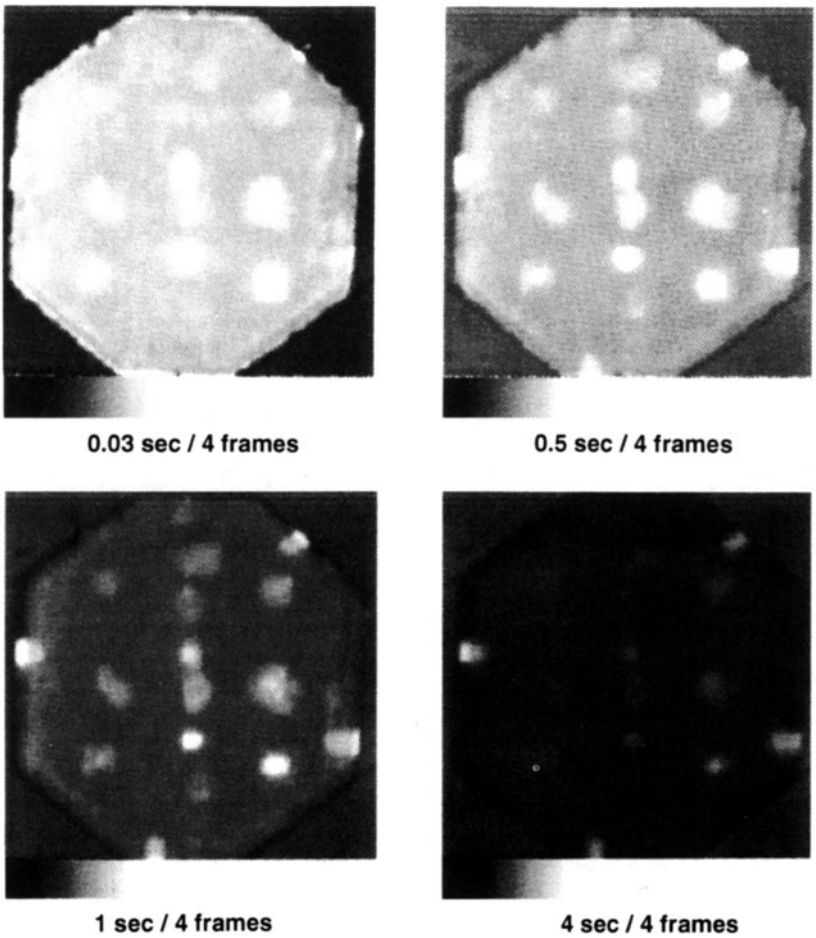

Fig. 5 Thermal wave images of a boron-epoxy composite patch on the B737 testbed, showing the thermal wave reflections from the artificial defects, from regions of weak bonding above some of the fasteners along the stringer, and (at later gate times) from the stringer and frame station beneath both the patch and the fuselage skin.

CONCLUSIONS

Thermal wave imaging techniques are emerging as a useful diagnostic tool for NDE of aircraft structures, both metallic and composite aircraft structures. They have the ability to image large areas in short times. The current inspection speed enables the imaging of over 90 feet of a 16" strip of aircraft per hour, and can be used to detect and image the presence of subsurface corrosion and disbonding.

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